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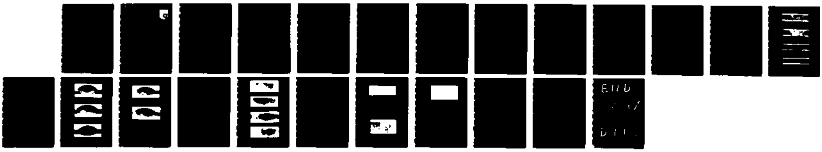

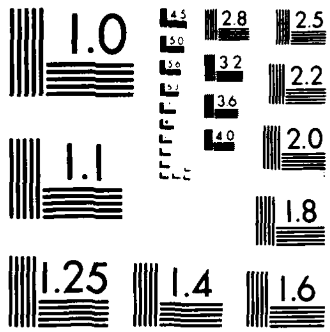

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GAS TUNGSTEN ARC WELDING OF Al-10Fe-5Ce

Guinn E. Metzger, Ph.D

Structural Metals Branch
Metals and Ceramics Division

February 1987

Final Report for Period June 1983 - June 1986

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MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6533

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This technical report has been reviewed and is approved for publication.

Guinn E. Metzger

GUINN E. METZGER
Project Engineer
Structural Metals Branch
Metals & Ceramics Division

FOR THE COMMANDER

FRANCIS H. FROES
Chief, Structural Metals Branch
Metals & Ceramics Division

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Thin sheet of the powder metallurgy aluminum alloy Al-10Fe-5Ce was fusion welded with the gas tungsten arc welding process. The effect of preweld vacuum heat treatment, filler metal, and the type of welding current was investigated.

The gross porosity of welds made with untreated base metal was virtually eliminated by the use of a combination of preweld vacuum heat treatment and a direct current electrode negative (DCEN) welding arc with helium shielding gas. The required heat treatment is estimated to be 20 hours at 750 F, which results in a reduction in the base metal tensile strength from about 65 to 60 ksi.

However, the presence of brittle phases near the weld interface causes low ductility and low strength. The tensile elongation at room temperature of longitudinal welds was about 1%, and the tensile strength joint efficiency of transverse welds was 55% when tested at room temperature, and 81% at a testing temperature of 600 F.

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FOREWORD

This report was prepared by Dr. G. Metzger, Structural Metals Branch, Metals and Ceramics Division, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. The research was performed under Project No. 24180207, "Structural Metals".

The report covers work performed during the period June 1983 through June 1986.

The author wishes to express his appreciation to Mr. Tom Jones, Mr. Travis Brown, and Mr. Joseph Brown, all of Westinghouse Electric Corporation, for conducting the welding experiments and associated tasks.

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SECTION I

INTRODUCTION

Recently developed aluminum alloys, produced by powder metallurgy methods, have higher strength at elevated temperature than aluminum alloys produced by conventional means. Joining of these powder metallurgy alloys is one of the requirements for their efficient application in structures. A feasibility study of the gas tungsten arc welding of one of these alloys, a metastable Al-10Fe-5Ce, is presented in this report.

It has long been recognized that fusion welds in powder metallurgy aluminum alloys are prone to the formation of excessive gas porosity, caused by the presence of hydrogen, as hydroxide or water, in the base metal. The hydrogen content may be reduced by heat treatment of the aluminum alloy in vacuum at high temperature. However, the heat treatment is limited by the reduction of base metal strength as the time and temperature increase.

SECTION II

MATERIALS

The base metal used in this investigation was the aluminum alloy, Al-10Fe-5Ce, consolidated from powder by extrusion to form a bar of rectangular cross section, 3/4 by 4-in. All welding and tensile testing was done with strips, 1/16 x 3/4 x 4-in., made by cutting perpendicular to the longitudinal axis of the bar, followed by machining to the 1/16 in. thickness.

Vacuum fusion analysis yielded a hydrogen content of 2 ppm, which was reduced to 1 ppm by treatment in a vacuum at 750 F for 100 hours.

Filler metals included Classifications ER4043 (5% Si), ER4047 (12% Si), and ER5356 (5% Mg) of the American Welding Society specification AWS A5.10-80.

SECTION III

BASE METAL TENSILE PROPERTIES

Tension specimens, as shown in Figure 1, were tested. There was a strong tendency for the specimens to fracture near the end of the 1-in. gage length, thus making it impossible to determine the elongation. This problem was solved by using an unconventional procedure (Reference 1). The entire length of the reduced section was subdivided at 0.1-in. intervals by marking with a scribe before tensile testing. Figure 2A illustrates a tension specimen with the fracture near the end of the 1-in. gage length. Dimension a represents the extended gage length that would be used for calculation of the elongation, if the specimen had fractured near the center of the gage length. Dimension b of Figure 2B represents the extended gage length that is used to compensate for fracture near the end of the gage length, and is composed of three elements. Dimension c of five scribe marks, which is one-half of the extended gage length on the longer end of Figure 2A; dimension d of two scribe marks, which is the distance between the scribe mark nearest the fracture and the end of the gage length on the shorter end of Figure 2A; and dimension e of three scribe marks, to complete the required ten scribe marks of dimension b of Figure 2B.

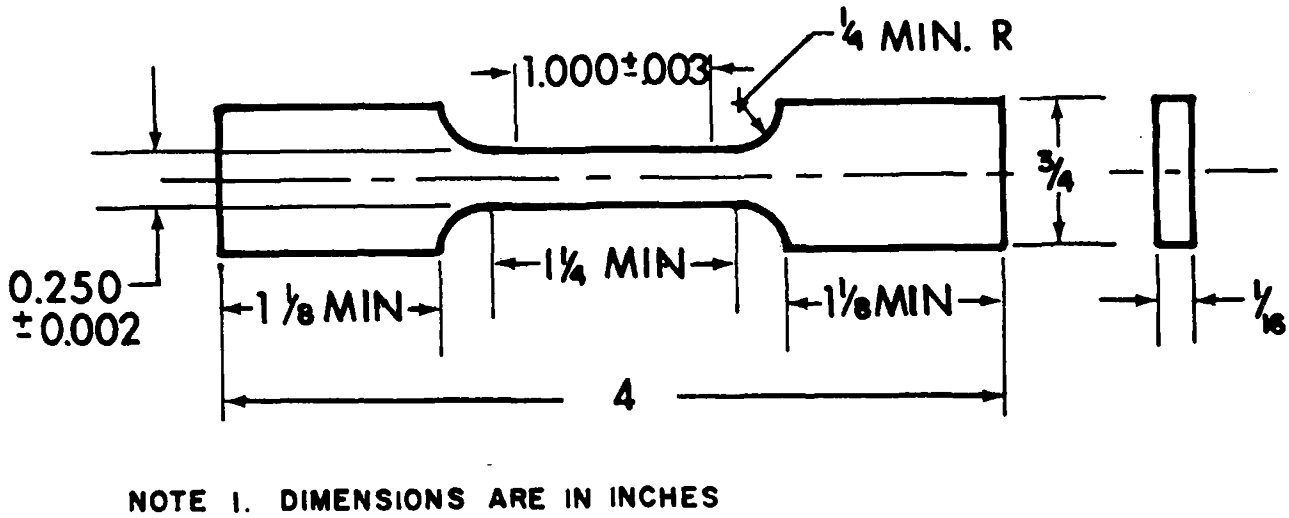


Fig. 1. Tension specimen

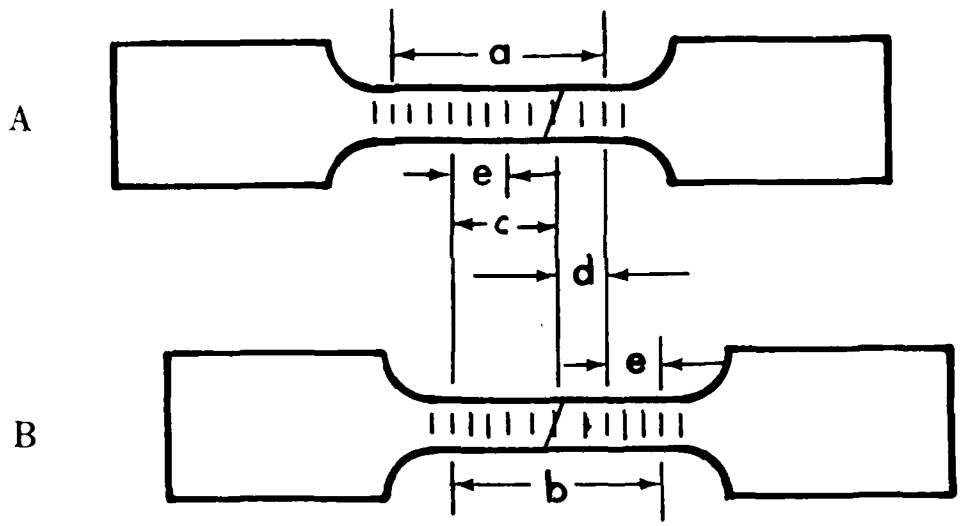


Fig. 2. Calculation of tensile elongation

The results of base metal tension tests are presented in Table 1. The holding time before testing was not recorded. The results are in good agreement with those reported by Lockheed (Reference 2) for the same alloy, except that a tensile strength at 600 F of 32 ksi was reported. Since that value is consistent with the results of extensive testing of a series of Al-Fe-Ce alloys by Lockheed, it is considered that 32 ksi is more accurate than the 50-52 ksi shown in Table 1.

One tension specimen, No. 16, tested after heat treatment at 750 F for 100 hours in air, had a tensile strength very near that of Nos. 13, 14, and 15, which were heat treated at the same time and temperature, but in vacuum. This indicates that, at these heat treatment conditions, air and vacuum have about the same effect on tensile strength.

Figure 3 shows, in graphical form, the effect of heat treatment at 750 F in vacuum on the tensile strength.

TABLE 1

RESULTS OF BASE METAL TENSION TESTS

tension specimen no.	heat treatment temp. F	time h	atmosphere	test temp. F	yield strength ksi	tensile strength ksi	elong. %*
1				RT		67	
2				RT		62	
3				RT	51	66	7.9
4				RT	53	66	7.5
5				400		57	
6				400		57	
7				600		52**	
8				600		50**	
9	750	20	vacuum	RT		62	
10	750	20	vacuum	RT		61	
11	750	50	vacuum	RT		54	
12	750	50	vacuum	RT		55	
13	750	100	vacuum	RT		51	
14	750	100	vacuum	RT		51	
15	750	100	vacuum	RT	35	49	
16	750	100	air	RT	37	48	10

* Elongation in 1-in. gage length
** See text, page 2

SECTION IV

WELDING

Specimens were machine welded in a clamping fixture with the gas tungsten arc welding (GTAW) process, with shielding gas supplied both to the welding torch and to the weld root. The only preweld surface preparation of the base metal strips was degreasing in acetone.

4.1 WELDS MADE WITH ALTERNATING CURRENT (AC)

4.1.1 Autogeneous welds

The first group of welds was made to obtain preliminary information on the effect of preweld heat treatment on weld porosity. Welds were made with no filler metal, with argon shielding gas, and in the flat position along the longitudinal axis of the base metal strip. Alternating current (AC) of 115-120 amperes (A) as the welding current, 15-18 volts (V) as the arc voltage, and a welding speed of 5 in./min were used to obtain a depth of fusion through the strip thickness.

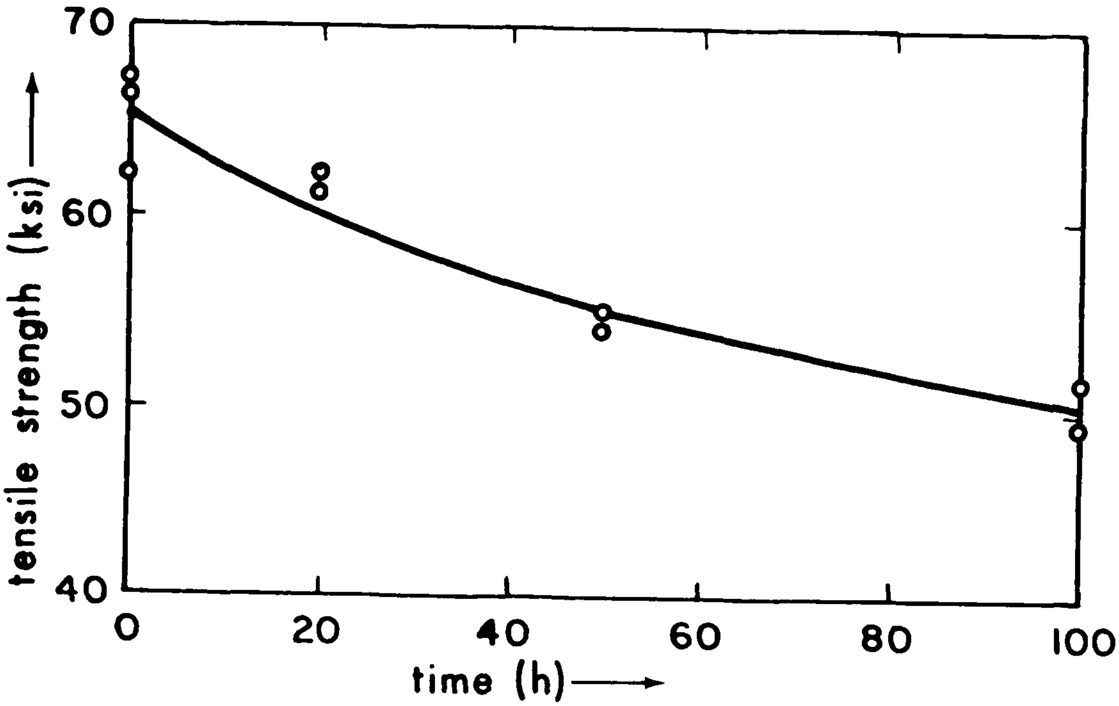


Fig. 3. Base metal room temperature tensile strength vs. heat treatment time at 750 F in vacuum

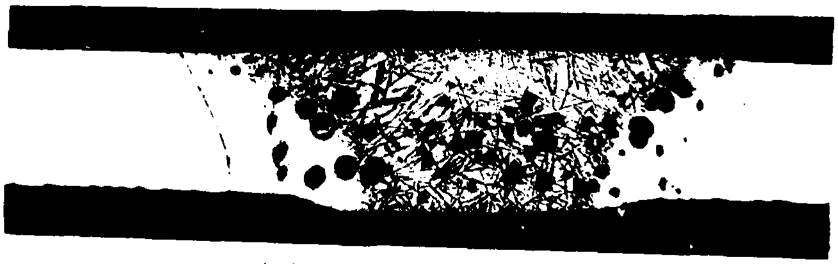
Preweld heat treatment of the base metal strips included exposure at temperatures of both 600 and 750 F for times of 10 and 100 hours in vacuum and 10, 100, and 1000 hours in air.

The welded strips were radiographed, and then cut perpendicular to the longitudinal axis into four 1-in. segments. Each of the three resulting cross sections was examined as a metallographic mount. Radiographs made with a variety of exposure conditions did not prove to be useful as a means of examination for weld porosity.

The excessive porosity of a typical cross section of a weld made with no preweld heat treatment is shown in Figure 4. A typical cross section of a weld made after a preweld heat treatment at 750 F for 1000 hours in air is presented in Figure 5. Although heat treatment in air caused a reduction in the pore size, there appeared to be little change in the porosity volume. Welds made with base metal that had been heat treated in air at 750 F for less than 1000 hours, as well as at 600 F, yielded about the same porosity results as shown in Figures 4 and 5.

A preweld heat treatment in vacuum at 750 F for 100 hours resulted in welds with a marked decrease in the porosity volume, when compared to no preweld heat treatment, but 100 hours at 600 F resulted in little or no improvement.

The encouraging results with base metal heat treated at 750 F in vacuum led to a second group of welds with preweld heat treatment using those conditions at 10, 20, 50 and 100 hours. The welding conditions were the same as for the first group. Photomicrographs of typical cross sections, prepared as described for the first group



no etchant 11X

Fig. 4. Autogeneous weld made with no preweld heat treatment, AC

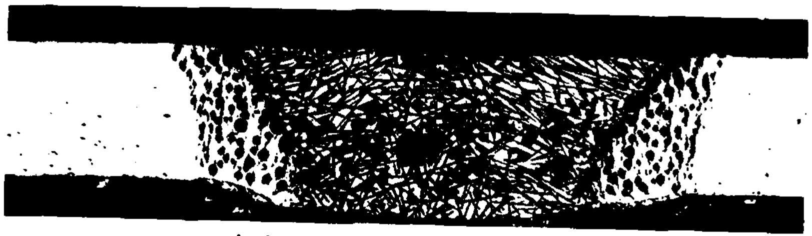


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Fig. 5. Autogeneous weld made with preweld heat treatment at 750 F for 1000 hours in air, AC

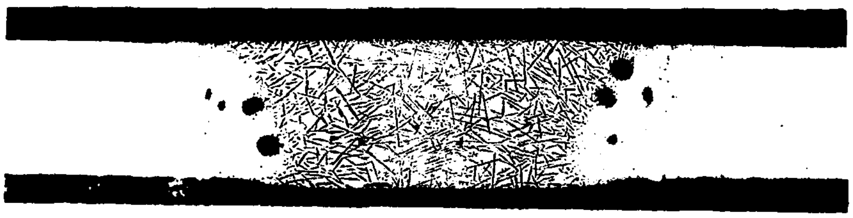

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Fig. 6. Autogeneous weld made with preweld heat treatment at 750 F for 10 hours in vacuum, AC

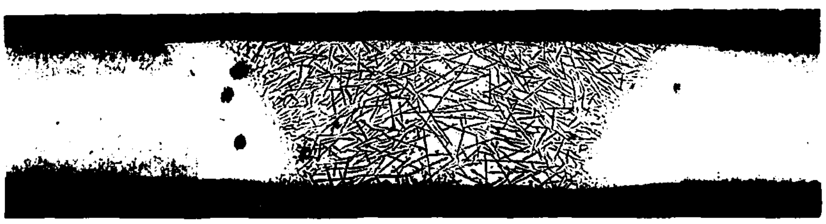

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Fig. 7. Autogeneous weld made with preweld heat treatment at 750 F for 100 hours in vacuum, AC

of welds, illustrating the beneficial effect of vacuum heat treatment at 750 F, are presented in Figure 6 for a 10 hour heat treatment and in Figure 7 for 100 hours. Welds in base metal with the 20 hour heat treatment were about the same as those for 10 hours, and welds with 50 hours were about midway between those for 10 hours and 100 hours. It is noted that most of the porosity in these welds is located in a zone near the weld interface.

4.1.2 Welds made with filler metal

A third group of welds was made to determine the effect on weld porosity of a combination of preweld heat treatment at 750 F in vacuum and the use of filler metal. The welding conditions were the same as for the first group, except as shown in Table 2. Preparation of the welds for metallographic examination was the same as for the first group.

TABLE 2

WELDING CONDITIONS FOR WELDS MADE WITH AC AND WITH FILLER METAL

weld no.	HT time* h	filler metal	arc voltage V	welding current A
1	none	ER4043	18	125
2	none	ER4047	21	135
3	none	ER5356	15	165
4	10	ER4043	18	125
5	10	ER4047	21	135
6	10	ER5356	15	165
7	100	ER4043	18	125
8	100	ER4047	21	135
9	100	ER5356	15	165

* Preweld heat treatment at 750 F in vacuum

A representative selection of photomicrographs from these welds is presented in Figures 8 through 12. Figures 8 and 9 illustrate the typical excessive porosity of welds made with no preweld heat treatment of the base metal. However, the upper part of the weld, consisting mostly of filler metal, is almost free of porosity. The porosity in the weld made with ER4047 was about the same as those made with ER4043 and ER5356.

Figures 10 through 12 illustrate the typical low porosity in welds made with preweld heat treatment at 750 F for 100 hours. Welds made with ER4043 and ER5356 had about the same amount of porosity as autogeneous welds (Figure 7), and were much better than welds made with ER4047. Again, the porosity was confined mostly to the weld metal zone containing a high proportion of base metal.

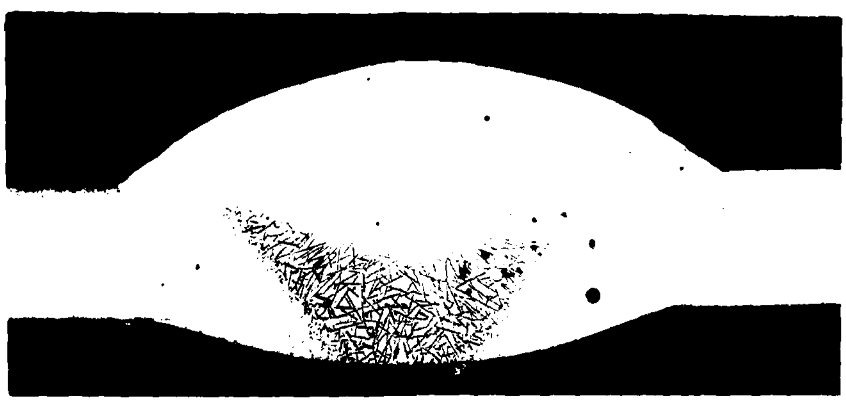
There was no significant decrease in porosity for welds made with preweld heat treatment at 750 F for 10 hours, as compared to no preweld heat treatment.

no etchant 11X

Fig. 8. Weld made with no preweld heat treatment, AC, ER4043

no etchant 11X

Fig. 9. Weld made with no preweld heat treatment, AC, ER5356

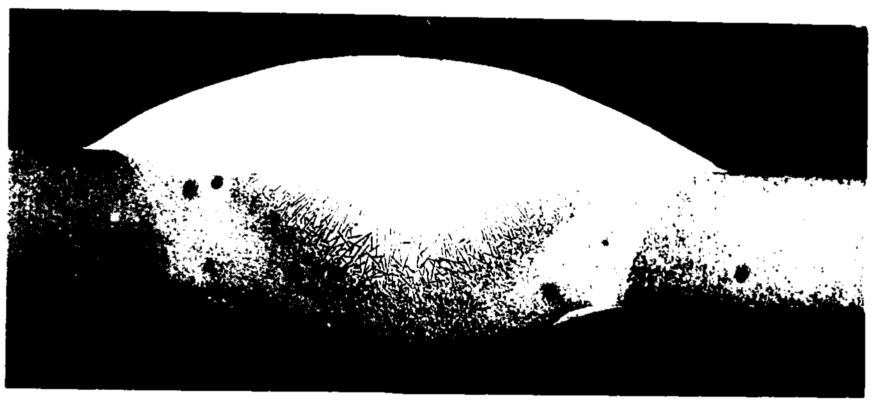


no etchant 11X

Fig. 10. Weld made with preweld heat treatment at 750 F for 100 hours in vacuum, AC, ER4043

Alcoa (nitric, hydrofluoric, chromic acids) etch 11X

Fig. 11. Weld made with preweld heat treatment at 750 F for 100 hours in vacuum, AC, ER4047



no etchant 11X

Fig. 12. Weld made with preweld heat treatment at 750 F for 100 hours in vacuum, AC, ER5356

4.2 WELDS MADE WITH DIRECT CURRENT ELECTRODE NEGATIVE (DCEN)

Welds were made in the flat position at a travel speed of 5 in./min, and with filler metal. Direct current electrode negative (DCEN) with helium shielding gas was used to obtain a depth of fusion through the base metal thickness.

The first group of DCEN welds, along the longitudinal axis of the base metal strip, was made to determine the effect of preweld heat treatment and filler metal on weld porosity. The welding conditions for these longitudinal welds are given in Table 3 for weld numbers 1 through 6. The filler metals selected were ER4043 and ER5356, since welds made with these filler metals and AC contained less porosity than those made with ER4047.

TABLE 3

WELDING CONDITIONS FOR WELDS MADE WITH DCEN

weld no.	HT time* h	weld** orientation	filler metal	arc voltage V	welding current A
1	none	coincident	ER4043	15	150
2	none	coincident	ER5356	14	185
3	10	coincident	ER4043	15	150
4	10	coincident	ER5356	14	185
5	100	coincident	ER4043	15	150
6	100	coincident	ER5356	14	185
7	none	coincident	ER5356	14	160
8	none	coincident	ER5356	13	150
9	none	transverse	ER5356	15	160
10	none	transverse	ER5356	15	160
11	none	transverse	ER5356	15	160
12	none	transverse	ER5356	18	140
13	none	transverse	ER5356	18	140
14	none	transverse	ER5356	18	140

* Preweld heat treatment at 750 F in vacuum

** Relationship of weld axis to longitudinal axis of base metal strip

A representative selection of photomicrographs of these welds is shown in Figures 13 through 16. The use of direct current resulted in a remarkable decrease in weld porosity, as compared to alternating current, for welds made with no preweld heat treatment; and, an appreciable decrease for welds made with preweld vacuum heat treatment. The weld illustrated in Figure 14 appears to indicate that weld porosity is virtually eliminated, when DCEN and ER5356 is used with a preweld heat treatment in vacuum at 750 F for 100 hours.

Other significant differences are the much more thorough mixing of base metal and filler metal in the weld metal, and the greater uniformity, along the weld length, in the width and height of the root reinforcement in welds made with direct current. In addition, welds made with ER5356 filler metal had slightly less weld porosity than those made with ER4043 and welds with a preweld heat treatment of 10 hours also had slightly less weld porosity than those made with no preweld heat treatment.

SECTION V

WELD TENSILE PROPERTIES

Welds were made in the flat position at a travel speed of 5 in./min, and with ER5356 filler metal. Direct current electrode negative (DCEN) with helium shielding gas was used to obtain a depth of fusion through the base metal thickness. There was no preweld heat treatment.

Alcoa (nitric, hydrofluoric, chromic acids) etch 11X

Fig. 13. Weld made with no preweld heat treatment, DCEN, ER5356

Alcoa (nitric, hydrofluoric, chromic acids) etch 11X

Fig. 14. Weld made with preweld heat treatment at 750 F for 100 hours in vacuum, DCEN, ER5356

no etchant 11X

Fig. 15. Weld made with no preweld heat treatment, DCEN, ER4043

no etchant 11X

Fig. 16. Weld made with preweld heat treatment at 750 F for 100 hours in vacuum, DCEN, ER4043

Two welds were made along the longitudinal axis of the base metal strip, and six welds were made transverse to the longitudinal axis and at the center of the base metal strip. The welding conditions for the two longitudinal welds are given with weld numbers 7 and 8, and for the six transverse welds with weld numbers 9 through 14 in Table 3.

The transverse welds were made by clamping a group of abutting strips, with machined straight edges, in the welding fixture and welding the entire group in one pass. This resulted in holes at some of the abutting edges, but sufficient undamaged welded strips remained to serve as tension specimens. Weld numbers 9 through 11 were in one group and 12 through 14 were in a second.

Tension specimens, as shown in Figure 1, were made from weld numbers 7 through 14. The weld reinforcement was removed by milling from the two specimens with longitudinal welds, but not from the six with transverse welds. The results of the tension tests are shown in Table 4, with the specimen numbers corresponding to the weld numbers of Table 3.

TABLE 4

RESULTS OF WELD TENSION TESTS

tension specimen no.	weld* orientation	test temp. F	yield strength ksi	tensile strength ksi	elong. %**	joint efficiency % ****
7	coincident	RT	18	20	0	
8	coincident	RT	19	20	1.6	
9	transverse	RT		36		55
10	transverse	RT		***		
11	transverse	400		33		52
12	transverse	400		26		
13	transverse	600		22		81
14	transverse	600		30		

* Relationship of weld axis to longitudinal axis of base metal strip

** Elongation in 1-in. gage length

*** Specimen broke upon installation in tensile testing machine

**** A ratio, expressed in percent, of the average weld tensile strength to the average base metal tensile strength from Table 1, except that the base metal strength of 32 ksi at 600 F, determined by Lockheed, was used in the calculation.

Fracture of the transverse weld tension specimens occurred at the weld interface, through the zone containing the weld porosity. An examination of the fracture surfaces with a binocular microscope revealed considerably more weld porosity (see Figure 17 for a typical example), as would be expected, than was evident in a cross section of a weld made with similar welding conditions (see Figure 13).

Fig. 17. Weld porosity on fracture surface of tension specimen with transverse weld (16X)

An examination of the fracture surfaces of the specimens with longitudinal welds indicated the formation of massive and closely spaced needles in the weld metal immediately adjacent to the weld porosity zone, as illustrated in Figure 18, and then sometimes a zone containing needles in rosette form, as illustrated in Figure 19. The orientation of the weld in both figures is with the weld face at the top of the photographs. The primarily fine-grained central portion of the weld metal is located at the left in Figure 18 and at the right in Figure 19. At the lower right corner of Figure 18, which is located at the edge of the specimen and also at the weld root, a few pores may be observed.

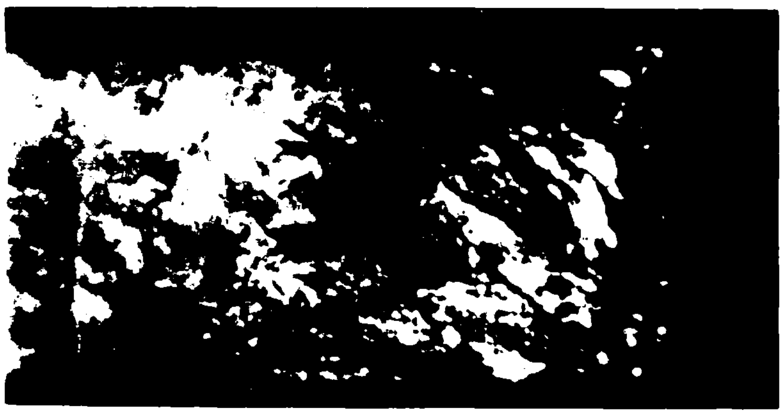


Fig. 18. Massive and closely spaced needles on fracture surface of tension specimen with longitudinal weld (32X)

Fig. 19. Needles in rosette form on fracture surface of tension specimen with longitudinal weld (32X)

The low tensile strength of the welds is considered to be normal, even when any effect of weld porosity is ignored. The gage section of the specimens with longitudinal welds is composed almost entirely of weld metal, which is an alloy of the lower strength ER5356 and the base metal. The high temperature experienced by the heat-affected zone during welding causes an agglomeration of the finely dispersed intermetallic particles that are primarily responsible for the high strength of the base metal. This results in low strength of the specimens with transverse welds, although it is expected that the weld porosity also contributed to the low strength.

There are several indications of brittle behavior in the results of the weld tension tests. The addition of the high ductility ER5356 filler metal to the base metal should result in an increase of weld metal ductility; yet just the opposite is true. The average ductility of the longitudinal weld tension s ecime umbers 6 and 7 of Table 4) is about one order of magnitude less than the average ity of the base metal (numbers 3 and 4 of Table 1). This decrease in ductility o great to be attributed to the presence of a few pores on the weld cross sectio he failure of number 10 upon clamping in the tensile test fixture is a good indi f poor weld ductility. The increased joint efficiency at a testing temperature of 600 F is consistent with the fact that the effect of brittle behavior is often alleviated with an increase in temperature. And finally, the needles found on the fracture surfaces of the longitudinal weld tension specimens have the appearance of iron-aluminum intermetallic compounds. The brittle behavior of intermetallic compounds would cause premature failure and low ductility.

SECTION VI

DISCUSSION

The first welds made with the type of welding current (alternating current, AC) most commonly used for the gas tungsten arc welding (GTAW) of aluminum, and with no filler metal, exhibited gross porosity distributed throughout the weld metal, when there was no preweld heat treatment and also when preweld heat treatment consisted of heating in air from a minimum exposure of 10 hours at 600 F to a maximum of 1000 hours at 750 F. Although preweld heat treatment in vacuum at 600 F did not appreciably affect the weld porosity, 750 F did drastically reduce the weld porosity, even at a time as short as 10 hours. Rather than being scattered about throughout the weld metal, the porosity was confined to the zone immediately adjacent to the weld interface, where the short time in the liquid state, a temperature of the weld pool close to the melting point, and a rapid solidification rate resulted in the entrapment of gas bubbles.

There was a poor correlation between the hydrogen content of the base metal and weld porosity. A vacuum heat treatment at 750 F for 100 hours reduced the hydrogen content from 2 to 1 ppm; i. e., the hydrogen was reduced by one half. However, the weld porosity reduction was an estimated two orders of magnitude. Apparently, there is something in the base metal, in addition to the hydrogen determined by vacuum fusion analysis, that causes weld porosity; or, the hydrogen analysis was not accurate.

The porosity in welds made after a preweld heat treatment of the base metal in vacuum at 750 F for 100 hours is probably acceptable; however, the decrease in the tensile strength of the base metal from about 65 to 50 ksi caused by this treatment is not. Therefore, further weld experiments were made with three widely-used commercial filler metals, again with AC, in an attempt to reduce weld porosity, and at the same time reduce the effect of the preweld heat treatment on the base metal strength.

Although the addition of filler metal did reduce weld porosity, it was still excessive, when there was either no preweld heat treatment or in vacuum at 750 F for [illegible] hours. The shallow penetration of the AC welding arc resulted in a weld bead that consisted primarily of filler metal at the weld-face side and primarily of base metal at the weld-root side. The greater agitation of the weld pool on the weld-face side permitted gas bubbles to escape, whereas the more stagnant weld metal on the weld-root side caused evolving gas to be entrapped, to form weld porosity. Welds made with a preweld heat treatment in vacuum at 750 F for 100 hours and with ER4043 and [illegible] filler metals exhibited about the same weld porosity volume as autogeneous welds made with the same preweld heat treatment, but the pores were located within the portion of the weld metal consisting primarily of base metal, rather than in a zone near the weld interface.

With the objective of more uniform weld metal, the deeper penetration of the [illegible]-shielded direct current electrode negative (DCEN) arc was used to make welds with [illegible] and [illegible] filler metals in base metal with no preweld heat treatment and with preweld heat treatment in vacuum. The objective was attained, but of much greater significance was the remarkable decrease in weld porosity. Welds with no preweld heat treatment had about the same amount of porosity as welds made with AC and a preweld heat treatment in vacuum at [illegible] F for [illegible] hours, and porosity was virtually eliminated in welds with ER[illegible] filler metal and a preweld heat treatment [illegible] hours. The greater agitation through the entire depth of the weld metal, [illegible] deeper penetration of the [illegible]-shielded DCEN arc, not [illegible] allowed [illegible] evolving gas to escape, except [illegible] a few bubbles entrapped near the weld interface, where molten time is short and solidification is rapid. An additional benefit of DCEN was better uniformity, along the weld length, in the width and height of the root reinforcement.

Transverse welds and longitudinal welds for tensile testing were made with DCEN, ER5356, and no preweld heat treatment. The fracture surfaces of tension specimens with a transverse weld, which failed near the weld interface through the zone containing weld porosity, revealed sufficient porosity to have some effect on the weld strength. Since either DCEN or preweld heat treatment in vacuum at 750 F for 100 hours resulted in welds with almost no porosity, it is probable that a combination of DCEN and preweld heat treatment for a time less than 100 hours would result in welds also no significant porosity. It is estimated that the necessary time would be on the order of 20 hours, with a corresponding decrease in the base metal tensile strength from about 65 to about 60 ksi.

However, a major deficiency in the welds, the presence of brittle phases in a zone of about 60 mils thickness near the weld interface, remains. If the thickness of a brittle layer can be limited to no more than a few mils, a weld will often exhibit good ductility. There is no possibility that welding at a greater travel speed to reduce the heat input would reduce the brittle zone to that thickness. It is also improbable that the lower heat input of plasma arc welding or electron beam welding would have sufficient effect on the thickness of the brittle zone to appreciably improve weld ductility.

SECTION VII

CONCLUSIONS

Fusion welds made by the GTAW process in powder metallurgy Al-10Fe-5Ce base metal are not useful for structural applications. Although weld porosity can be virtually eliminated by a combination of DCEN welding and preweld vacuum heat treatment, with only a minor decrease in base metal tensile strength, the welds exhibit a brittle behavior due to brittle phases formed near the weld interface.

It is believed that welds made by any fusion welding process would be useful only for sealing welds, or some other non-structural application.

REFERENCES

1. Eisenkolb, F., Einfuehrung in die Werkstoffkunde. Band II. Mechanische Pruefung Metallischer Werkstoffe, VEB Verlag Technik, Berlin, 1961, pp. 30-32.

2. Langenbeck, S. L. et al, "Elevated Temperature Aluminum Alloy Development", LR 30377, Lockheed-California Company, Dec. 1982

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